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# Livelihood assets' influence on Ugandan farmers' control practices for Banana Xanthomonas Wilt (BXW)

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## Abstract

This study analyzes the influence of livelihood assets on Ugandan farmers' decisions to control Banana Xanthomonas Wilt (BXW), a disease that has threatened banana production and the livelihoods of Ugandan farmers since 2001. The BXW control strategy is based on the simultaneous implementation of four cultural practices: de-budding, infected plant removal, disinfecting tools, and using clean planting materials. The Sustainable Rural Livelihood (SRL) framework represents a very useful theoretical architecture for examining the interplay between livelihood systems of rural Ugandan households and the external context. Empirically, this study applies a double-hurdle model with the base assumption that the two adoption decision processes (whether to adopt and the intensity of adoption of the cultural practices) are separate. Results indicate that the vulnerability context and the human, social, natural, and physical capitals are the factors that drive farmers to adopt the identified strategy. Farmers' decisions about the extent of adoption are instead negatively influenced by natural capital and positively associated with social capital. These findings highlight the importance of supporting the improvement of livelihood assets to enable tailored support to farmers. It is particularly important to support the social and natural capitals that facilitate information exchange and provide critical resources for the adoption of the BXW control strategy.

**Keywords:** Banana Xanthomonas Wilt, Livelihood assets, Sustainable livelihoods framework, Uganda

## Introduction

As in other developing countries, banana production contributes significantly to the food security and household income of rural people in Uganda. It is estimated that 75% of Ugandan households grow the crop, while Ugandans' per capita consumption of bananas is the highest in the world (Karamura 1993). Besides being an important staple food and cash crop, bananas are also valued for their medicinal properties and are associated with many cultural ceremonies and traditional beliefs. Alarming, banana production in Uganda has been severely threatened by Banana Xanthomonas Wilt (BXW) since 2001 (Tushemereirwe et al. 2003). This disease often leads to

complete crop loss and there are currently no banana varieties that are resistant to BXW (Karamura et al. 2010; Kubiriba and Tushemereirwe 2014).

During Uganda's first BXW peak, the incidence in affected fields reached up to 70% in a one-year period (Kalyebara et al. 2006), while in 2013, during the second peak, the incidence rate was over 50% (National Banana Research Program Website 2015). As a result, many households abandoned banana cultivation (Tushemereirwe 2001). Employment opportunities were lost, while the scarcity of bananas sharply increased their prices, making it increasingly difficult for local consumers to purchase their main source of nutrition (Karamura et al. 2010; Vurro et al. 2010). The situation in Uganda was only declared under control in 2015, with just 1.9% of households showing BXW symptoms in their fields (Vurro et al. 2010). However, there is a high risk of BXW resurgence. The study by Tinzaara et al. (2016) reported that the disease had continued to spread not only into disease-free areas, but also to areas where BXW had previously been declared under control. This could be due to the survival of latently infected planting materials (Ocimati et al. 2013), the fact that the disease can rapidly increase to endemic levels (Nakakawa et al. 2017), or due to banana-growing households lacking a clear understanding of the factors that impact the spread of the disease (Tinzaara et al. 2016). Considering the vital role that banana production holds for the livelihoods of rural Ugandan people, it is crucial to bring BXW under control, or preferably eradicated.

In a joint effort with various international, national, and local organizations, the Ugandan government identified the farming practices that are most effective in limiting the disease's spread and consequent yield losses (Blomme et al. 2017). The integrated set of control practices identified were: (a) de-budding with a forked stick, (b) disinfecting tools with fire or Jik, (c) removal of infected plants (whether cutting out the single stem affected or the whole mat), and (d) replanting using clean planting material in the form of tissue-culture plantlets or macro-propagated plantlets (Kubiriba and Tushemereirwe 2014; Kubiriba et al. 2014; Tripathi et al. 2009; Tushemereirwe et al. 2006). This integrated BXW control package was widely promoted throughout the country in order to inform households about how BXW spreads, to promote available control options and to boost proper adoption of these practices (Kubiriba and Tushemereirwe 2014). The resurgence of BXW can only be prevented by sustained adoption of this package; these practices keep the incidence of the disease at manageable levels. Consequently, understanding the factors influencing farmers' adoption behaviors is critical to effectively controlling BXW.

This study aims to contribute to this issue by investigating the relationship between Ugandan farmers' livelihood assets and their adaptation practices to control BXW. To this end, the Sustainable Rural Livelihood (SRL) framework is employed in the current study. This holistic framework focuses on the livelihood systems of poor rural households and how they adapt their farming strategies to address external stressors, while preserving their livelihoods (Scoones 1998). The SRL framework is rarely implemented in agricultural innovation adoption studies. A common feature of such studies is that they theoretically build upon the farmers' utility maximization framework, while empirically implementing binary or censored data models with the common assumption that whether to adopt or not and the intensive margins (how much to adopt) are considered as a unique process. While such assumptions may be valid, there is no reason to expect

this a priori. Therefore, to overcome this limitation, a double-hurdle model (Cragg 1971) is implemented to identify the factors that influence farmers’ decision to adopt or not adopt the innovation and separately examine the factors that influence the intensity of adoption. The results of the current study could offer a more comprehensive perspective on farmers’ decision-making processes and provide insights for more effective political intervention, thereby ensuring an adequate level of BXW mitigation by Ugandan farmers.

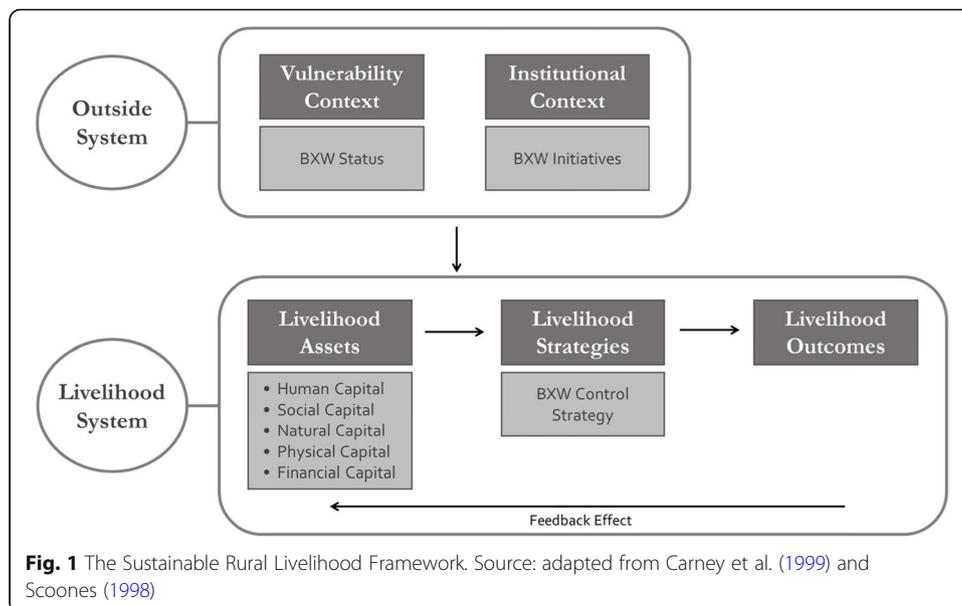
This study is organized as follows: the “Methodological approach” section introduces the theoretical framework and the empirical approach employed, while the “Results” and “Discussion” sections show and discuss the results achieved. The final section presents our concluding remarks.

### Methodological approach

#### Theoretical framework

Recognition that BXW has severe consequences for the livelihoods of rural households has stimulated the identification of an effective strategy to maintain the disease incidence at manageable levels. Merely having the strategy is not sufficient; the promotion of the strategy and the understanding of the factors influencing its adoption are both critical for the effective control of BXW.

Given the above considerations, the Sustainable Rural Livelihood (SRL) framework (Fig. 1) is adopted as the theoretical architecture of this study. The framework centers on rural households’ livelihood systems, which are based on assets and strategies employed by farmers with the purpose of improving their livelihood outcomes. However, livelihood systems must interact with the outside system, which is composed of the vulnerability context and the institutional context (Scoones 1998). Changes in the outside system will lead to alterations in the internal equilibrium of the livelihood system. The SRL framework therefore offers a broader view of the decision-making



**Fig. 1** The Sustainable Rural Livelihood Framework. Source: adapted from Carney et al. (1999) and Scoones (1998)

process of rural households. It highlights that the strategies adopted by rural households are decisions internal to the livelihood system aimed at improving their livelihoods, while households may adapt their strategies in response to shocks that might occur from the outside system.

By considering the integrated package of the four cultural practices (de-budding, disinfecting tools, removal of infected plants and use of clean planting material) as a strategy for rural households to manage the adverse impacts on income and food security caused by the BXW disease, the SRL framework has been adapted to understand what livelihood assets influence Ugandan farmers' strategies, and how their choices are impacted by the outside context. The findings could provide insight for more effective political interventions and consequently ensure an adequate level of adaptation to BXW, or its control, by rural households.

To operationalize the SRL within the context of our case study, we collected data on farmers' livelihood assets, BXW status on households' farms, access to the BXW communication approaches promoted by the institutional context, as well as data on the agricultural practices adopted by rural farmers to limit the spread of the disease. The next paragraph outlines in finer detail the empirical approach employed in the current analysis.

### **Sample and data collection**

The data used in this study is drawn from a survey conducted between April and May 2018, aimed at establishing farm typologies for effective targeting, promotion, and sustainable adoption of BXW control practices among banana farming households in Uganda.

The sampling method follows a previous BXW incidence and management survey conducted in 2015. The survey was administered through face-to-face interviews using a pre-tested questionnaire. The enumerators were well trained and had previous experience in conducting banana surveys. The respondents were located in four selected major banana-growing and consuming regions (i.e., Central, Eastern, Mid-Western and South-Western) of Uganda. From each region, three districts were randomly selected, with the exception of the Eastern region in which five districts were randomly selected. The 14 districts selected were as follows: Kayunga, Kiboga, and Luwero from the Central region; Bukedea, Kumi, Mbale, Kamuli, and Manafwa from the Eastern region; Kabarole, Masindi and Mubende from the Mid-Western region; and Bushenyi, Rukungiri, and Ntungamo from the South-Western region. Two major banana-producing sub-counties were purposely selected per district, with one parish from each sub-county randomly selected. At the parish level, three villages were randomly selected, with 15 households randomly selected per village from lists provided by the local council authorities. In total, 1058 rural households participated in the survey.

### **Empirical model variables**

For the empirical contextualization of the concepts embodied by the SRL framework, namely livelihood assets, livelihood strategies, and the outside context, this study identifies and defines the following variables.

### **Livelihood strategy**

Livelihood strategies are the combination of activities that households implement to achieve their livelihood goals (Stewart Carloni and Crowley 2005). In this case, the strategy that could be adopted by the Ugandan farmers to limit the spread of the BXW is based on the following four farming practices: (1) de-budding, (2) disinfecting tools, (3) removal of infected plants, and (4) use of clean planting material. Consequently, for the purposes of this analysis, the dependent variable will range from 0 to 4, according to the number of practices adopted by the households. The zero value refers to non-adopters, that is, smallholder farmers who have not practiced the BXW strategy at all. The other values that the dependent variable can assume (from 1 to 4) indicate the intensity of adoption of the recommended strategy. Households who applied only one practice scored “1,” those that applied two practices scored “2,” and those that applied three practices scored “3,” while households that applied all four practices were considered full adopters and scored “4.”

### **Livelihood assets**

Livelihood assets are a household’s resource base and are often grouped into human, social, natural, physical, and financial capitals (Ellis 2000). Different endowments of the foregoing may justify the pursuit of specific strategies by the household (Below et al. 2012; García de Jalón et al. 2018; Jezeer et al. 2019). To measure each of the five capitals, we chose a set of indicators based on literature and data availability. The selected variables and their expected influence on the adoption of the integrated BXW control strategy can be found in Table 1.

**Table 1** Livelihood assets selected and their expected influence on adoption of the BXW control strategy

<b>Livelihood assets</b>	<b>Expected influence</b>	<b>References</b>
<i>Human capital</i>		
HH head education (years)	+	Mignouna et al. 2011
HH head age (years)	–	Adesina and Zinnah 1993
HH size (number)	+	Mwangi and Kariuki 2015
<i>Social capital</i>		
HH head gender (1 male)	+	Doss and Morris 2001
Access to extension services (1 yes)	+	Peshin 2013
<i>Natural capital</i>		
Farm location	+/-	Otieno et al. 2011
Land owned (acres)	+	Deressa et al. 2009
Land banana percentage	+	Jogo et al. 2013
<i>Physical capital</i>		
Home index	+	Kuntashula et al. 2015
Farm equipment index	+	Shinbrot et al. 2019
<i>Financial capital</i>		
Banana farming objective	+	Kikulwe et al. 2019
Access to credit facilities (1 yes)	+	Tambo and Abdoulaye 2012
Off-farm income (1 yes)	+	Reardon et al. 2007

To measure human capital, we included the (1) age, (2) level of education of the household head, and (3) number of household members in the analysis. A negative effect of age on adoption is usually expected, since older farmers have been found to be typically more risk-averse and less interested in long-term farm investments than younger farmers (Adesina and Zinnah 1993). A higher level of education influences farmers' attitudes and thinking, making them better able to acquire, synthesize, and use information about the problems they face and the possible solutions they can adopt (Mignouna et al. 2011; Waller et al. 1998). Lastly, the number of family members in the household is used as a proxy for availability of labor. It positively impacts the adoption process because a larger household has greater capacity to overcome the labor constraints required for the introduction of a new practice (De Souza Filho et al. 1999; Mignouna et al. 2011; Mwangi and Kariuki 2015). Larger households have the human capital that allows them to adopt labor-intensive activities (Feder et al. 1985).

For social capital, we used two variables: (1) gender of the household head and (2) access to extension services. Gender can influence strategy implementation because the household head is the primary decision maker. Gender-linked disparities in access to inputs, resources and services, due to socio-cultural values and norms, can impact these strategic decisions (Doss and Morris 2001; Hassan and Nhemachena 2008; Mignouna et al. 2011; Omonona et al. 2006; Tenge et al. 2004). In Uganda, it is expected that male-headed households are more likely to adopt the promoted strategy than female-headed households. Additionally, interaction with extension agents greatly increases farmers' knowledge of available technologies and their potential benefits, hence acting as a trigger mechanism for intensive adoption (Peshin 2013). Therefore, this study hypothesizes that access to extension services positively influences the introduction of the new strategy.

To measure natural capital, we selected the following variables: (1) the farm's location, since regional differences can influence farmers' adoption decisions (Adeoti 2008; Kikulwe et al. 2019; Otieno et al. 2011), (2) the total farm area, as larger farms are associated with greater wealth and it is expected that larger-scale farmers have the means to take adaptive measures and the capacity to bear risks (Deressa et al. 2009; Langyintuo and Mulugetta 2008; Nyangena 2007), and (3) the proportion of land allocated to banana production as a proxy for the importance of banana as a food and income crop (Jogo et al. 2013). Investments in adaptation options to BXW disease have a greater chance of uptake when farmers give high importance to banana production. Consequently, a positive correlation is expected between the proportion of land allocated to banana production and the adoption of the BXW control strategy.

For the physical capital-related variables, the type of (1) house and (2) farm equipment<sup>1</sup> used by the households were considered, because they denote a certain level of household well-being, which positively correlates to the likelihood of adopting adaptation measures (Grootaert et al. 1997; Kuntashula et al. 2015).

Finally, the financial capital was measured using (1) the banana farming objective<sup>2</sup> (subsistence or commercial) as a proxy of the centrality of the crop to farmers'

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<sup>1</sup>Composite indices constructed using factor analysis, calculated separately for household characteristics and farm assets.

livelihoods (Kikulwe et al. 2019); the (2) ownership of off-farm income sources; and (3) access to credit facilities were also measured because they represent important strategies for overcoming liquidity constraints faced by many rural households in developing countries (Reardon et al. 2007). Households with access to these different sources of income will have the financial resources needed to introduce new agricultural activities in their farms and hence are expected to adopt the recommended strategy more readily.

### **Outside context**

The SRL framework includes two sets of external forces that are beyond the control of the household, but that are able to influence households' livelihood outcomes: the vulnerability context and the institutional context. The concept of vulnerability refers to unpredictable shocks that can negatively impact households' assets and consequently their livelihood strategies (Adato and Meinzen-Dick 2002). To represent this aspect of the framework, the current analysis used a variable related to the BXW status of households' farms. This variable ranges from 0 to 4, based on how long ago BXW was observed on the households' farm. Zero values indicate that BXW was last observed more than a year ago (i.e., low disease status), value 1 indicates that the BXW was last observed less than 6 months ago, value 2 indicates that the BXW was last observed less than 3 months ago, value 3 indicates that the BXW was last observed less than a month ago, while value 4 indicates that the BXW is still present on the farm.

The institutional context refers to outside policies and processes that mediate the ability to implement specific strategies. The institutional context leads to the adoption of specific strategies for managing the negative impacts caused by external stressors (Adato and Meinzen-Dick 2002). Since several studies have shown that information and knowledge about innovative agricultural practices are important determinants of adoption (e.g., Aïtchédji et al. 2010; Katungi and Akankwasa 2010), various communication approaches have been used in Uganda. These approaches aimed to develop the knowledge and skills of the farmers related to the integrated BWX control strategy and, ultimately, to mobilize them for its adoption. A variable to quantify access to the BXW communication approaches was incorporated into the analysis, to assess whether they have indeed been able to influence the adoption decisions of smallholder farmers. This variable is measured as "1" if the households have participated in trainings, farmers' field schools or community actions or zero if otherwise.

### **Empirical approach**

In this study, a double-hurdle model is used to analyze the ways in which the five capitals (viz. human, social, natural, physical, and financial) and the outside context influence the decision and intensity of adoption of the BXW control strategy.

A feature of many models of adoption is that the process that leads to the decision of whether to adopt is assumed to be the same that determines the intensity of adoption. However, this is not always the case; decisions about whether to adopt and how much to adopt can be taken together or separately (Gebremedhin and Swinton 2003). The double-hurdle model, originally from Cragg (1971), is based on the idea that an individual's decision is the result of two processes. The first hurdle is to determine whether

the individual is a zero type, and the second hurdle is to determine the intensity of adoption if the individual is not a zero type.

As mentioned above, the recommended strategy to be adopted by Ugandan farmers to limit the spread of BXW is based on four farming practices. For the purposes of this analysis, the dependent variable will range from 0 to 4, according to the number of practices adopted by the households. Since the peculiarity of the data-generating process, a Poisson-logit hurdle model (Hilbe 2014) accounting for a count process is implemented with the following characteristics: (a) a binary process for explaining positive counts versus zero counts (i.e., 1 versus 0) that is related to the decision of whether to adopt the recommended strategy; (b) a positive count process for modeling the intensity of the adoption of the practices comprising the BXW control strategy (counting from 1 to 4). Following Hilbe (2014), the first process is modeled using a logit model, while the second is modeled employing a zero-truncated Poisson model.

## Results

Table 2 indicates that among the four recommended BXW control practices, removal of infected plants was the most frequently employed practice, with approximately 58% of households adopting this practice. Half of the sampled households practiced timely removal of male buds with a forked stick, while 38% of households used fire or Jik to disinfect their tools. For households that implemented only one practice of the integrated package, the most adopted was de-budding (55%). Adoption rates of the different practices differed when considering households that implemented two or three practices. In these cases, the most adopted practices were the removal of diseased plants and the disinfection of agricultural tools.

Replanting using clean planting material, in the form of tissue-culture plantlets or macro-propagated plantlets, was by far the least adopted practice, with just 1% of the sample employing this strategy. Previous studies (e.g., Gotor et al. 2020; Jogo et al. 2013; Kikulwe et al. 2019) tend to exclude this practice from the analysis precisely because it represents such low levels. The use of clean planting material is considered optional compared to the other practices recommended in the integrated BXW control package, because it is only required if the rural household decides to replant banana,

**Table 2** Adoption level of recommended practices to control the spread of the BXW as part of Ugandan banana-growing households' livelihood strategy

BXW control practices	All sample (obs. 1058) Mean (SD)	Non-adopters (0 practices) (obs. 235) Mean (SD)	1 practice (obs. 319) Mean (SD)	2 practices (obs. 277) Mean (SD)	3 practices (obs. 225) Mean (SD)	Full-adopters (4 practices) (obs. 2) Mean (SD)	F test <sup>1</sup>
De-budding (1 yes)	0.50 (0.50)	0.00 (0.00)	0.55 (0.50)	0.43 (0.50)	0.99 (0.09)	1.00 (0.00)	206.26***
Disinfecting tools (1 yes)	0.38 (0.49)	0.00 (0.00)	0.01 (0.11)	0.62 (0.49)	1.00 (0.00)	1.00 (0.00)	682.41***
Removal of infected plants (1 Yes)	0.58 (0.49)	0.00 (0.00)	0.41 (0.49)	0.94 (0.24)	1.00 (0.07)	1.00 (0.00)	453.99***
Clean planting material (1 yes)	0.01 (0.10)	0.00 (0.00)	0.01 (0.08)	0.01 (0.10)	0.01 (0.11)	1.00 (0.00)	66.20***

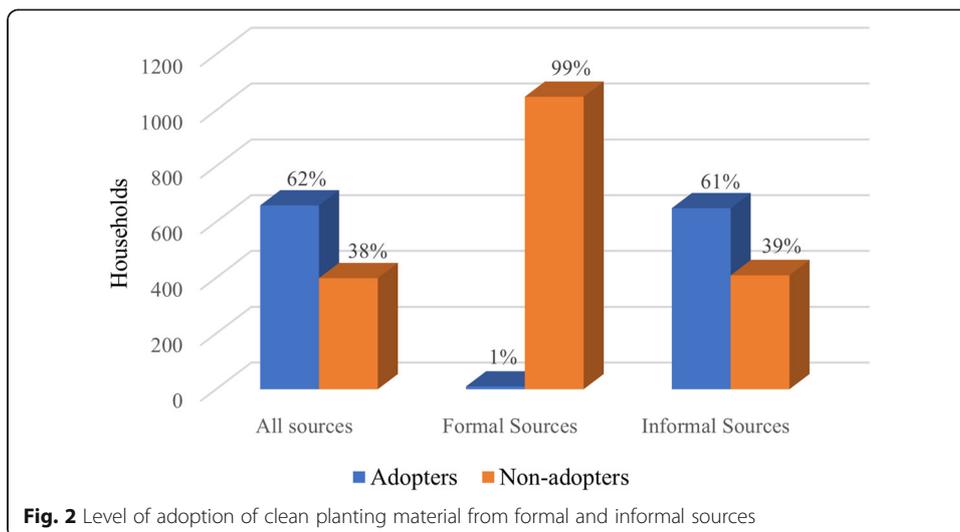
<sup>1</sup>One-way ANOVA. Level of significance: \*10%; \*\*5%; \*\*\*1%. Values in parentheses are standard deviations (SD)

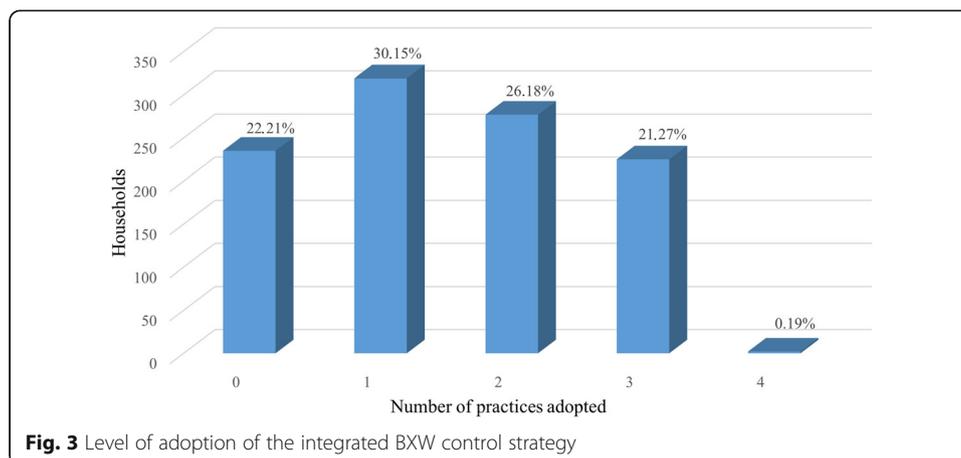
which is not always the case. However, about two thirds (62%) of the sampled farmers did replant new banana plants (Fig. 2).

Such a high percentage shows that, for rural Ugandan households that are growing new banana plants to replace infected ones, the source of the plantlets remains an issue. Most of these farmers preferred to source suckers from existing mats on their own farm because they were familiar with these plants and could thus predict performance and properties of the sucker. If, for whatever reason, farmers could not use suckers from their own field, they then preferred to source planting materials from within their own social networks (Kilwinger et al. 2019). In fact, the informal source of inputs (such as farmer-to-farmer exchange) was preferred by 61% of the sampled farmers (Fig. 2) as the cost is lower than when buying from formal sources (Bagamba et al. 2006; Staver et al. 2010). However, this socio-cultural practice based on the exchange of plantlets rather than on their purchase through the formal sector aggravates the problem because it increases the risk of spreading BXW (McC Campbell et al. 2018; Tinzaara et al. 2013). Just 1% of all the sampled households use clean planting material from the formal sector, indicating that this practice’s adoption has been sporadic, at best, across Uganda. This makes the eradication of the disease a very intricate challenge and further highlights the importance of understanding the underlying reasons for a rural household’s full adoption of the recommended package of disease control practices. This is why the present study includes the use of clean planting material from the formal sector in its analysis, despite its extremely low incidence (1%).

Focusing on the complementary adoption of the four aforementioned practices, Fig. 3 illustrates that full adopters of the BXW control strategy represent only 0.19% of the sample (2 smallholders over the total 1,058 surveyed), while non-adopters amount to approximately 22% of the sample size (235 rural households). Partial adopters embody the remaining 77.60% of the sample.

The group of non-adopters is made up of rural households who allocate just a small percentage (approximately 26%) of their land to the cultivation of bananas, mainly destined for self-consumption (Table 3). In addition, this group has the highest level of farm equipment index compared to all the other groups (namely 47.20) but has low well-being levels and limited access to both agricultural services and information on





BXW. Indeed, the group of non-adopters shows the lowest scores for the home index (which is an indicator of the households' well-being), access to extension services, and BXW initiatives (only 10%). Conversely, the group of full adopters report the highest values in terms of land owned (viz. a mean value of 6.25 acres) and farming objective (a mean value of 2.50). This indicates that the full adopters' agricultural production is more market-oriented than the other groups. Notably, full adopters have high levels of well-being, but the lowest scores for farm equipment and access to credit facilities. Regarding geography, the regional differences between each level of adoption are significant. As for the non-adopters, half (51%) are located in the Eastern region and only 11% are located in the South-Western region. On the contrary, partial adopters are mostly present in the South-Western region, while they are far less numerous in the Eastern region. Finally, the full adopters are present only in the Central region. At the bottom of the table, information is provided about the BXW status of the farms and the households' access to the communication approaches promoted in Uganda to control the disease's spread. Households who adopt only two or only three practices present high disease status scores (3.04), indicating that, on average, BXW was last observed less than 3 months ago on their farms. The full adopters and households that adopted only three practices present the higher scores denoting greater access to institutional initiatives to limit the spread of the disease.

Estimates on the influence of livelihood assets and the outside context on Ugandan farmers' strategies are shown in Table 4<sup>3</sup>. Since the first hurdle of the model implemented in this study estimates the probability of zero (i.e., no adoption), the results of the logit model show that the region where the rural households are located, the age of the household head and the farm equipment increase the likelihood that not even one practice will be adopted. Conversely, access to extension services, the percentage of land used for banana production and the vulnerability context reduce the odds of non-adoption of the recommended livelihood strategy. Regarding the determinants of the

<sup>3</sup>In addition to the model presented in this study, a second model following Kikulwe et al. (2019) was implemented, which only considered three practices: de-budding, removal of infected plants, and disinfection of agricultural tools. The results of this model were substantially similar to the results of the full model implemented in this analysis. Summary statistics and results of the second model can be found in Tables 5 and 6 in the [appendix](#).

**Table 3** Descriptive statistics of the explanatory variables

Explanatory variables	All Sample	Non-adopters	1 practice	2 practices	3 practices	Full-adopters	F test <sup>1</sup>
	(obs. 1058)	(obs. 235)	(obs. 319)	(obs. 277)	(obs. 225)	(obs. 2)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
<i>Human capital</i>							
HH head education	5.95 (3.91)	5.94 (3.83) a	6.25 (4.13) a	5.57 (3.84) a	6.03 (3.74) a	5.50 (0.71) a	1.16
HH head age	56.62 (14.46)	57.58 (14.82) ab	54.59 (14.25) b	58.47 (14.86) a	56.20 (13.53) ab	59.00 (19.80) ab	3.05**
HH size	6.37 (3.14)	6.48 (3.60) a	6.35 (3.20) a	6.24 (2.84) a	6.43 (2.90) a	7.50 (0.71) a	0.28
<i>Social capital</i>							
HH head gender	0.74 (0.44)	0.74 (0.44) ab	0.71 (0.46) b	0.71 (0.46) ab	0.80 (0.40) a	1.00 (0.00) ab	2.22*
Access to extension services	0.54 (0.50)	0.49 (0.50) b	0.54 (0.50) ab	0.52 (0.50) b	0.64 (0.48) a	0.50 (0.71) ab	2.69**
<i>Natural capital</i>							
Central region	0.22 (0.41)	0.16 (0.37) b	0.27 (0.45) c	0.20 (0.40) bc	0.20 (0.40) bc	1.00 (0.00) ac	20.10***
Eastern region	0.20 (0.40)	0.51 (0.50) a	0.16 (0.37) c	0.10 (0.30) bc	0.08 (0.26) b	0.00 (0.00) abc	
Mid-Western region	0.23 (0.42)	0.22 (0.42) ab	0.27 (0.44) a	0.26 (0.44) b	0.16 (0.37) ab	0.00 (0.00) ab	
South-Western region	0.35 (0.48)	0.11 (0.31) d	0.29 (0.46) c	0.44 (0.50) b	0.56 (0.50) a	0.00 (0.00) abcd	
Land owned	4.51 (7.19)	4.67 (8.00)	4.24 (5.48)	4.34 (4.77)	4.94 (10.29)	6.25 (1.77)	0.40
Land banana percentage	41.52 (31.07)	26.29 (32.02) a	44.76 (30.41) b	47.05 (29.91) b	46.14 (27.36) b	31.15 (18.80) ab	19.80***
<i>Physical capital</i>							
Home index	38.54 (21.44)	36.50 (22.14)	39.93 (20.26)	39.17 (21.18)	37.88 (22.64)	44.74 (15.24)	1.02
Farm equipment index	43.47 (21.19)	47.20 (20.93) a	44.13 (22.71) ab	42.24 (19.82) b	40.26 (20.37) b	34.08 (15.82) ab	3.56***
<i>Financial capital</i>							
Banana farming objective	1.79 (0.63)	1.66 (0.67) b	1.81 (0.64) a	1.78 (0.58) ab	1.91 (0.59) a	2.50 (0.71) ab	5.22***
Access to credit facilities	0.70 (0.46)	0.69 (0.47) ab	0.66 (0.47) b	0.70 (0.46) ab	0.79 (0.41) a	0.50 (0.71) ab	2.88**
Off-farm income	0.88 (0.33)	0.94 (0.23) a	0.87 (0.34) b	0.86 (0.34) b	0.84 (0.37) b	1.00 (0.00) ab	3.37***
<i>Vulnerability context</i>							
BXW status	1.98 (1.75)	0.22 (0.84) a	1.61 (1.84) b	3.04 (1.20) c	3.04 (1.04) c	2.00 (1.41) abc	185.45***
<i>Institutional context</i>							
Access to BXW initiatives	0.22 (0.41)	0.10 (0.30) c	0.22 (0.41) b	0.20 (0.40) b	0.35 (0.48) a	0.50 (0.71) abc	11.24***

<sup>1</sup>One-way ANOVA. Level of significance: \* 10 %; \*\* 5 %; \*\*\* 1 %. Values in parentheses are standard deviations (SD). Different letters within each row indicate significant differences at the 0.05 level (Fisher-Hayter pairwise comparisons test)

**Table 4** Results of the Poisson-logit hurdle model

<i>Variables</i>	<i>First hurdle</i>			<i>Second hurdle</i>		
	<i>Coef.</i>	<i>SE</i>	<i>p value</i>	<i>Coef.</i>	<i>SE</i>	<i>p value</i>
<i>Human capital</i>						
HH head education	− 0.026	0.028	0.342	− 0.009	0.007	0.212
HH head age	0.017	0.008	0.028	0.002	0.002	0.361
HH size	− 0.033	0.030	0.268	0.007	0.009	0.430
<i>Social capital</i>						
HH head gender	0.039	0.255	0.878	0.140	0.067	0.037
Access to extension services	− 0.460	0.222	0.038	0.072	0.057	0.208
<i>Natural capital</i>						
Central region	0.635	0.359	0.077	− 0.254	0.075	0.001
Eastern region	1.892	0.363	0.000	− 0.524	0.119	0.000
Mid-Western region	0.670	0.353	0.058	− 0.293	0.078	0.000
Land owned	− 0.021	0.014	0.137	0.002	0.003	0.485
Land banana percentage	− 0.009	0.004	0.034	− 0.002	0.001	0.030
<i>Physical capital</i>						
Home index	− 0.005	0.005	0.371	− 0.001	0.001	0.301
Farm equipment index	0.009	0.005	0.056	− 0.002	0.001	0.112
<i>Financial capital</i>						
Banana farming objective	− 0.176	0.175	0.315	0.065	0.047	0.170
Access to credit facilities	− 0.023	0.239	0.922	0.104	0.068	0.130
Off-farm income	0.147	0.352	0.676	0.018	0.073	0.803
<i>Vulnerability context</i>						
BXW status	− 1.139	0.114	0.000	–	–	–
<i>Institutional context</i>						
Access to BXW initiatives	− 0.461	0.328	0.159	–	–	–
<i>Constant</i>	− 0.762	0.799	0.340	0.325	0.193	0.093

intensity of adoption, the results of the second hurdle of the model indicate that the gender of the household head positively and significantly influences this decision. As for the proportion of land area allocated to banana production, its coefficient is significant and negative. Similarly, from the results of the model, it is possible to observe that the coefficients of the dummy regions are all negative and significant.

## Discussion

BXW disease has threatened banana production and the livelihoods of Ugandan farmers since 2001. The strategy identified to keep disease incidence at manageable levels is based on the simultaneous application of four cultural practices. However, full adopters of the BXW control strategy represent only 0.19% of our sample, while non-adopters are approximately 22% of the sample. The implementation of a double-hurdle model made it possible to deepen the understanding of the phenomenon under examination. As expected, there are different sets of livelihood assets underlying the decision to adopt and how many practices to adopt. Farming households' decisions about adoption of at least one BXW control practice are associated with human, social, natural,

and physical capitals, as well as the vulnerability context. Instead, farmers' decisions about the extent of adoption are influenced by social and natural capitals.

Among the human capital-related variables, the age of the household head increased the odds of non-adoption. Its effect is thought to stem from the fact that as farmers grow older, there is a higher risk aversion and a lower consideration of long-term investments in the farm. This is especially true for those farmers closer to retirement (Mwangi and Kariuki 2015). Conversely, young farmers generally want to gain experience and are therefore more willing to try out new technologies (Adesina and Zinnah 1993; Mauceri et al. 2005).

The results of the first hurdle further indicate that physical capital is positively and significantly associated with the likelihood of non-adoption. A reasonable explanation would be the substitution in adaptation options, as some wealthier farmers may prefer to adopt coping strategies (such as completely abandoning banana production and growing other crops) over the recommended adaptation strategy (García de Jalón et al. 2018).

An interesting aspect to consider is that social and natural capitals are the only livelihood assets that cause significant variations in the two adoption decision processes (adoption and intensity of adoption). Among the social capital-related variables, interaction with extension services is an important factor that counteracts the likelihood of non-adoption of the BXW control strategy. This is because the frequency of contact between farmers and extension personnel makes information on new technologies available and accessible to farmers. Additionally, interaction with extension agents could counterbalance the negative effect generated by the farmers' poor level of formal education (Yaron et al. 1992). Instead, the gender of the household head positively and significantly influences how many practices will be adopted. Male-headed households are likelier to adopt more practices against BXW compared to their female counterparts. This result is in line with earlier studies designating gender to be a significant and positive influence on the adoption of improved agricultural technologies (Doss and Morris 2001; Hailu et al. 2014; Kikulwe et al. 2018; Morris and Doss 1999; Murage et al. 2015; Uaiene 2011). Gender issues in agricultural technology adoption have been investigated extensively, indicating that gender is a key factor for determining adoption and scaling of agricultural technologies in developing countries (Morris and Doss 1999). Explanations for the influence of gender on technology adoption often include references to socio-cultural values and norms that reinforce men's role as the primary decision maker (Kazianga and Wahhaj 2013; Lambrecht et al. 2018). Gender norms are unwritten social rules that influence women's and men's behavior and practices in the household and on the farm. These norms significantly influence how women and men maximize opportunities related to agricultural production and innovation (Iradukunda et al. 2019; Rietveld and Farnworth 2018). Gender-linked disparities are particularly evident regarding access to inputs, income and knowledge, all of which are critical aspects of innovation (Doss and Morris 2001; Mignouna et al. 2011; Omonona et al. 2006; Tiruneh et al. 2001). Most aspects of banana cultivation are largely controlled by men, who have more access to agricultural extension services and implement banana disease management practices more than women (Doss 2013; Iradukunda et al. 2019; Kikulwe et al. 2018).

In case of natural capital, all dummy regions are significant in both hurdles, indicating that regional differences significantly influenced decision and intensity of adoption of the control practices. On the one hand, farming households in the Central, Eastern, and Mid-Western regions are more likely to not adopt the BXW control strategy. On the other hand, they are less likely to adopt more than one practice compared to those in the South-Western region. These findings corroborate previous studies that highlight the relevance of regional differences (Adeoti 2008; Kikulwe et al. 2019; Otieno et al. 2011). A possible explanation is that banana production plays a prominent role for commercial purposes in the South-Western region and consequently there has been a greater involvement of all banana stakeholders in the fight against the disease.

The proportion of land allocated to banana production is another natural capital-related variable associated with both decision and intensity of adoption. The result of the first hurdle indicates that the larger the proportion of banana production, the less likely the farmer is to not adopt at least one of the BXW control practices, while the second hurdle indicates that this variable limits the intensity of adopting the disease control strategy. The first corroborates the assumption that farmers' willingness to eradicate the disease from their own farm is subject to the importance they attribute to bananas as a food and income crop; the second hurdle suggest that the adoption of the full package may be too demanding for farmers who have an extensive banana production.

Lastly, this study does not find any influence of financial capital on the decision to adopt or the intensity of adoption of the identified strategies. Broadly, financial capital is an indicator of farm-household wealth as it refers to the economic resources available to the household (Mutabazi et al. 2015). However, contention on how this capital affects adoption exists. For instance, García de Jalón et al. (2016) have shown that financial capital significantly and negatively influences the adoption of adaptation strategies, while Deressa et al. (2009) and Bryan et al. (2013) have found a positive correlation.

Focusing on the outside system, the vulnerability context counters the likelihood of non-adoption of the disease management strategy. This indicates that farmers are aware of this strategy, consider it effective and will therefore adopt it as an adaptive strategy to the shock coming from the outside system. However, rural households will only modify their farming practices when their banana production is being affected by the disease and not as a general practice. This could pose a problem as there is a strong possibility of disease resurgence.

As discussed before, the Ugandan government promoted the BXW control strategy through a range of communication approaches that sensitize households to the disease and mobilize them to correctly adopt the recommended practices. This is because acquiring information on a new technology allows farmers to learn about the existence and effective use of the practices and this facilitates their adoption. Other studies have shown farmers' participation in communication programs to be important in the adoption of new agricultural technologies (Aïtchédji et al. 2010; Bunyatta et al. 2006; Erbaugh et al. 2010; Kikulwe et al. 2019; Ooi and Kenmore 2005). In contrast, this study does not find a significant relationship between the variable related to the institutional

context (proxied by access to BXW communication initiatives) and the adoption of the livelihood strategy. This is may be because farmers have gathered conflicting messages on BXW management from different sources, which has led them away from appreciating the benefits behind the recommended strategy.

## Conclusions

This study contributes to the body of literature on crop disease and pest management by identifying the livelihood assets responsible for rural farmers' adoption of measures that mitigate BXW in Uganda. Theoretically, this study builds upon the Sustainable Rural Livelihood framework as it allows a more comprehensive view on how rural households adapt their farming practices to handle external stressors and preserve their livelihoods. Empirically, the double-hurdle class of models has been applied in this study with the underlying assumption that the two adoption decision processes (adoption and intensity of adoption) are separate. This model was applied to a sample of 1058 smallholder farmers located in four major banana-growing and -consuming regions of Uganda (i.e., Central, Eastern, Mid-Western and South-Western). Our analysis shows that the majority of the sampled households only partially adopted the BXW control strategy on their farms, making it difficult to eradicate the disease. Double-hurdle results indicate that factors that drive farmers to adopt the recommended control strategy were found to be the vulnerability context and the human, social, natural and physical capitals. Farmers' decision about the extent of adoption is instead negatively influenced by natural capital and positively associated with social capital. These findings highlight the importance of understanding and supporting the improvement of livelihood assets to enable tailored assistance to farmers. It is essential to back the livelihood assets of rural households in Uganda, as there is a strong possibility of disease resurgence. A new BXW outbreak could lead to heavy negative impacts on the livelihoods of rural households in Uganda. It is therefore important to prevent such an outbreak by encouraging policies that enhance the continuous adoption of the recommended BXW control strategy.

However, this study has some caveats that need to be considered. First, the choice of variables implemented in this study to describe and quantify the different components of the SRL framework was based on the relevant literature and the specific socio-cultural context being analyzed, yet the different components of the framework may not be fully covered by the selected variables. This is because the SRL framework has been long debated in the literature and consequently there is no unequivocal conceptualization of the framework and its components (Small 2007). Further research could expand on this. Secondly, it is worth noting that our study data were collected in 2018, when the BXW situation in Uganda was declared to be under control. Determinants of adoption of the BXW control strategy could be different during a disease outbreak and within different country contexts. With such limitations, there is a need for longitudinal research to assess the determinants of adoption of BXW control strategy across sub-Saharan Africa.

## Appendix

**Table 5** Adoption level of recommended practices to control the spread of the BXW as part of Ugandan banana-growing households' livelihood strategy

BXW control practices	All sample	Non-adopters	1 practice	2 practices	3 practices	F test <sup>1</sup>
	(obs. 1058)	(obs. 237)	(obs. 320)	(obs. 277)	(obs. 224)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
De-budding (1 yes)	0.50 (0.50)	0.00 (0.00)	0.57 (0.50)	0.43 (0.50)	1.00 (0.00)	284.16***
Disinfecting tools (1 yes)	0.38 (0.49)	0.00 (0.00)	0.01 (0.11)	0.63 (0.48)	1.00 (0.00)	924.29***
Removal of sick plants (1 yes)	0.58 (0.49)	0.00 (0.00)	0.42 (0.49)	0.94 (0.23)	1.00 (0.00)	621.72***

<sup>1</sup>One-way ANOVA. Level of significance: \*10%; \*\*5%; \*\*\*1%. Values in parentheses are standard deviations (SD)

**Table 6** Result of the Poisson-logit hurdle model

Variables	First hurdle			Second hurdle		
	Coef.	SE	p value	Coef.	SE	p value
<i>Human capital</i>						
HH head education	− 0.031	0.028	0.257	− 0.009	0.008	0.253
HH head age	0.015	0.008	0.050	0.001	0.002	0.437
HH size	− 0.036	0.030	0.223	0.007	0.009	0.449
<i>Social capital</i>						
HH head gender	− 0.016	0.252	0.949	0.127	0.067	0.060
Access to extension services	− 0.473	0.222	0.034	0.071	0.057	0.214
<i>Natural capital</i>						
Central region	0.599	0.360	0.096	− 0.268	0.075	0.000
Eastern region	1.931	0.365	0.000	− 0.512	0.120	0.000
Mid-Western region	0.639	0.354	0.071	− 0.302	0.079	0.000
Land Owned	− 0.009	0.013	0.490	0.003	0.002	0.258
Land banana percentage	− 0.009	0.004	0.035	− 0.002	0.001	0.035
<i>Physical capital</i>						
Home index	− 0.004	0.005	0.456	− 0.001	0.001	0.293
Farm equipment index	− 0.009	0.005	0.066	− 0.002	0.001	0.087
<i>Financial capital</i>						
Banana farming objective	− 0.175	0.175	0.319	0.058	0.047	0.217
Access to credit facilities	− 0.004	0.239	0.987	0.111	0.069	0.108
Off-farm income	0.145	0.352	0.680	0.019	0.073	0.798
<i>Vulnerability context</i>						
BXW status	− 1.143	0.115	0.000	−	−	−
<i>Institutional context</i>						
Access to BXW initiatives	− 0.471	0.327	0.149	−	−	−
Constant	− 0.623	0.804	0.438	0.350	0.193	0.070

**Abbreviations**

BXW: Banana Xanthomonas Wilt; HH: Household; SRL: Sustainable Rural Livelihood

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**Authors' contributions**

EG and FC designed the research framework; EK coordinated the data collection; and TP analyzed the data and discussed them together with FC and EK and EG. EG, TP, EK, and FC worked on the conclusions together. The authors read and approved the final manuscript.

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**Availability of data and materials**

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request and will also be soon made public available on DataVerse.

**Declarations****Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

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**Competing interests**

The authors declare that they have no competing interests.

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